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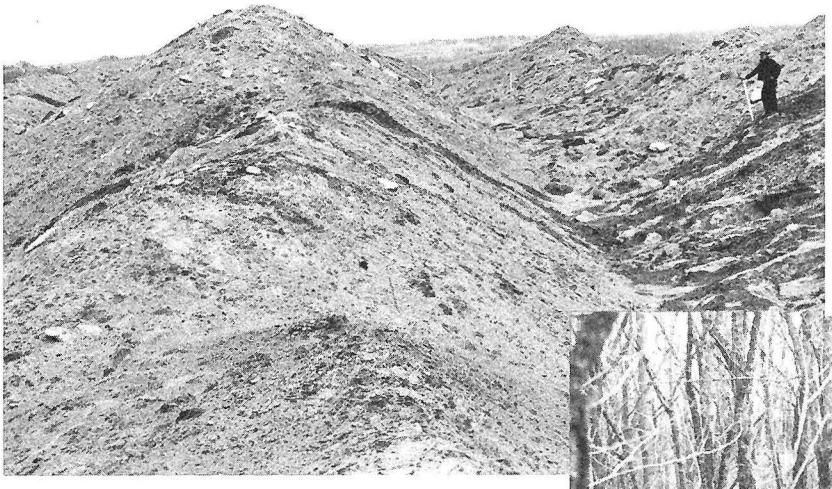

The Ohio State University
Ohio Agricultural Research and Development Center
Wooster, Ohio

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The authors acknowledge the cooperation of the Ohio Mining and Reclamation Association and its individual corporate members who permitted access to their lands. Employees and former employees of the association, including Donald Richter, William Dietrich, and William Augur, were instrumental in locating experimental plantings. Others involved in the field work were Gary Cline, Charlton Aten, and James H. Finney, all employees of the OARDC.

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Evaluation of 30-Year-Old Plantations on Stripmined Lands in East Central Ohio

M. M. LARSON and J. P. VIMMERSTEDT[1]

ABSTRACT

Thirteen experimental plantations established by the U.S. Forest Service in 1946-47 on stripmined land in eastern and southeastern Ohio were remeasured in 1975-76. Some major purposes of these plantings were to evaluate:

- Survival and growth of hardwoods and conifers on calcareous and non-calcareous spoils.
- Survival and growth of various tree species on graded and ungraded spoils.
- Effects of black locust interplanted at four ratios with tuliptree, red oak, or white oak.
- Effects of grass and legumes, seeded concurrently with tree planting, on establishment and growth of tree seedlings and on soil erosion.

Survival of all planted trees averaged 36.6% on calcareous spoil and 23.3% on non-calcareous spoil after 30 years. White and green ash survived best of the planted species; white pine was largest in diameter. Tuliptree was tallest of all species tested, but was sensitive to soil compaction by grading and had comparatively low survival. Black locust was effective in site stabilization but stand vigor is declining rapidly on most areas due to heavy borer damage to trees. Growth of hardwoods was not improved when planted in various mixtures with black locust. Pine and hardwood transplants tended to survive better than seedlings, although vigor of stock was more important than age or class.

Bur oak survival was outstanding among species direct seeded, especially when seeded on south slopes of spoil banks. Survival and growth of legume and grass ground cover was spotty, even during the earliest years, and its effects on associated trees were considered inconclusive. Soil compaction during grading reduced survival and growth of trees.

Results of these early studies demonstrate the potential of forest plantings as productive, permanent, protective cover on coal spoils. Problem areas requiring further research include:

1. Soil Compaction. Grading methods that minimize compaction and post-grading treatments that reduce compaction need to be developed.

2. Tree-Ground Cover Interaction. Tree species should be tested with various ground cover species in order to find combinations that are compatible with regard to competitive and allelopathic effects. Herbicide treatments for tree establishment also need to be tested.

3. Planting Stock Quality and Planting Methods. Survival of planted trees needs to be increased through improvement of seed and seedling quality, and development of improved planting methods.

INTRODUCTION

In the United States, some of the earliest reclamation of lands surface-mined for coal was accomplished by planting trees and, for the next 40-plus years, thousands of acres were successfully planted. Yet today, only a small fraction of stripmined land in Ohio is reclaimed by planting trees (10, 15). This is largely because mining law changes during the 1970's required extensive grading, replacement of stored "topsoil", and seeding of a temporary cover of small grains, grasses, or legumes after mining. Fulfilling the legal requirements of reclamation was accomplished more economically by establishing a quick-growing, dense, permanent herbaceous cover than by trying to establish forest cover together with grasses and legumes (9).

At a recent symposium,[2] many reclamation experts shared their concerns about the short-term site protection afforded by "herbaceous only" cover, and strongly recommended increased tree planting on mined lands. The unique advantages of planting trees on mined lands are well-known; these are long-term maintenance of environmental quality, production of forest products (sawtimber, posts, pulpwood, fuelwood, Christmas trees, nut crops), and provision of both recreation and wildlife habitat.

In 1946-47, the Central States Forest Experiment Station of the USDA Forest Service, Ohio Reclamation Association, Ohio Division of Forestry, and several private coal companies cooperated in establishment of planting and seeding studies on a variety of stripmined areas in eastern and southeastern Ohio. In 1975, 13 of these experimental plantations were still in existence (Fig. 1). Remeasurement of plantations was begun in 1975 and completed in 1976.

The authors believe these data of the Ohio plantations at age 30 contribute much to the knowledge of which tree species have the long-term potential for good survival and growth on stripmined lands. One limitation of this information for present-day use is that none of the 13 study plantations received unincorporated "topsoil" following mining. "Topsoiling" does not alter basic reforestation principles developed earlier, but the current requirements for both topsoiling and seeding of herbaceous species add new symbiotic, competitive, and allelopathic factors which alter tree performance and will require additional study and evaluation.

[1]Professor and Associate Professor, Dept. of Forestry.

[2]A symposium, Trees for Reclamation in the Eastern United States, Oct. 27-29, 1980, Lexington, Ky., sponsored by the Interstate Mining Compact Commission and the U.S. Dept. of Agriculture, Forest Service.

TABLE 1. — Description of 1946-47 Stripmine Plantations.

Plantation Exp. No.	Nearest Town	Year Established	Subplots, Number	Subplots, Size	Treatments and Tree Species
2	Mineral City	1946	16	70 ft x 70 ft	Leveled and unleveled spoils planted with 1-1 tuliptree, 3-0 red pine, 1-0 white ash, and 2-0 Chinese chestnut.
3	Georgetown	1946	36	105 ft x 105 ft	Leveled, partially leveled, and unleveled spoils planted with 1-1 tuliptree, 3-0 white pine, 1-0 black locust, and 2-0 white ash.
7	Dundee	1946	36	105 ft x 105 ft	Test of species and age classes of stock as follows: white pine (2-0, 3-0, 2-2), red pine (2-0, 3-0), tuliptree (1-0, 1-1), osage-orange (1-0), black walnut (seed), red oak (seed), white ash (2-0), and black locust (1-0).
7	Dundee	1946	12	105 ft x 105 ft	Tree species planted in mixtures, two species per subplot in alternate three-row groups as follows: 3-0 white pine and 1-0 black locust, 1-1 tuliptree and 1-0 black locust, 1-0 osage-orange and 1-0 black locust, red oak (seed) and 1-0 black locust.
7	Dundee	1946	3	105 ft x 105 ft	Two species planted in mixture: 3-0 red pine planted on upper one-third of ridges and 1-0 black locust on lower two-thirds of ridges.
7	Dundee	1946	3	105 ft x 105 ft	Three species planted in mixture in alternate one-row groups in the following order: 1-1 tuliptree, black walnut (seed), 1-0 black locust.
7	Dundee	1946	12	105 ft x 105 ft	Comparison of planting methods: 1-1 tuliptree and 2-2 white pine planted by bar-slit, side-hole, and center-hole methods.
7	Dundee	1947	30	52 ft x 105 ft	Test of tree species as follows: 1-0 red oak, 2-0 pitch pine, 2-0 shortleaf pine, 1-0 green ash, 1-0 tuliptree, 1-0 basswood, 1-0 white oak, 1-0 silver maple, 1-0 cottonwood, and cottonwood (cuttings).
8	Alliance	1946	36	70 ft x 70 ft	Test of species and age classes of stock as follows: white pine (2-0, 3-0, 2-2), red pine (2-0, 3-0), tuliptree (1-0, 1-1), osage-orange (1-0), black locust (1-0), white ash (2-0), black walnut (seed), and red oak (seed).
8	Alliance	1946	3	70 ft x 70 ft	Species planted in row by row mixtures (one species per row) in the following order: red oak (seed), 1-1 tuliptree, 1-0 black locust, 2-0 white ash, black walnut (seed).
8	Alliance	1946	3	70 ft x 70 ft	Comparison of fertilized and unfertilized trees. Species were 3-0 white pine, 1-1 tuliptree, and 2-0 white ash. Fertilized trees received 36 g dried meat scraps and 4 g K_2SO_4 mixed with planting soil.
10	Jewett	1947	6	28 ft x 350 ft	Test of three seeded ground covers and four tree species. Ground cover treatments were: 1) sericea lespedeza/orchardgrass 2:1 (wt/wt) at 34 lb/a, 2) yellow sweetclover at 22 lb/a, and 3) unseeded control. Each subplot planted with one row each of 1-0 green ash, 3-0 red pine, 1-0 tuliptree, and 2-2 white pine.
11	Bloomingdale	1947	6	28 ft x 350 ft	Test of three seeded ground covers and four tree species. Ground cover treatments were: 1) sericea lespedeza/orchardgrass 2:1 (wt/wt) at 34 lb/a, 2) yellow sweetclover at 22 lb/a, and 3) unseeded control. Each subplot planted with one row each of 1-0 green ash, 3-0 red pine, 1-0 tuliptree, and 2-2 white pine.
12	Mineral City	1947	4	28 ft x 350 ft	Same as Plantation 11 except without the yellow sweetclover ground cover treatment.

TABLE 1 (continued).—Description of 1946-47 Stripmine Plantations.

Plantation Exp. No.	Nearest Town	Year Established	Subplots, Number	Subplots, Size	Treatments and Tree Species
13	Zanesville	1947	4	28 ft x 350 ft	Same as Plantation 11 except without the yellow sweetclover ground cover treatment.
14	Georgetown	1947	36	105 ft x 105 ft	Test of black locust as a nurse crop for hardwoods. 1-0 white oak, 1-0 red oak, and 1-0 tuliptree, each planted with black locust at 1:0 (pure hardwood), 3:1, 1:1, and 1:3 ratios.
15	Zanesville	1947	36	105 ft x 105 ft	Same as Plantation 14.
16A	Jewett	1947	6	40 ft x 66 ft	North and south slopes of ungraded spoils seeded with the following 11 tree species: black walnut, black cherry, black locust, sycamore, white ash, jack pine, pitch pine, loblolly pine, shortleaf pine, bur oak, and eastern redcedar.
16B	Georgetown	1947	6	40 ft x 66 ft	Same as Plantation 16A.
17B	Zanesville	1947	6	40 ft x 66 ft	Same as Plantation 16A.

THE EXPERIMENTAL PLANTATIONS

An establishment report was prepared for each of the 13 plantations shortly after the trees were planted. These reports contained detailed location maps, subplot maps, treatment descriptions, photographs, and other information as to seedling stock, spoil conditions, and planting operations. A brief description of the plantations, species, and treatments is given in Table 1. Common names of species are used throughout this report; scientific names are listed in Appendix Table I.

Results of two earlier examinations of these plantations have been published. The first was based on third-year measurements (12) and the second on tenth-year measurements (8). These two reports also included data of three plantations that have since been lost to remining: Plantation 4 near Strasburg, Plantation 5 near Lisbon, and Plantation 6 near Cadiz.

Nine separate studies were conducted on the plantations. Six are identified as major studies and three as minor studies.

Major Studies

1. Comparison of survival and growth of selected hardwoods and conifers on calcareous and non-calcareous spoil types (all plantations).
2. Comparison of survival and growth of various tree species on leveled (graded) and unleveled (ungraded) stripmine spoils (Plantations 2 and 3).
3. Use of black locust as a nurse crop for fine hardwood species, and the determination of the best hardwood/black locust planting ratio (Plantations 14 and 15).
4. Effects of seeded legumes and grass at time of tree planting on soil erosion and on establishment and growth of tree seedlings (Plantations 10, 11, 12, and 13).
5. Comparison of survival and growth of direct seeded hardwoods and conifers on north and south aspects of ungraded spoilbanks (Plantations 16A, 16B, and 17B).
6. Effect of age class of nursery stock on establishment and growth of trees (Plantations 7 and 8).

Minor Studies

1. Comparison of cost and effectiveness of three tree planting methods (Plantation 7).
2. Growth of selected tree species planted in mixture as compared to their growth in pure stands (Plantations 7 and 8).

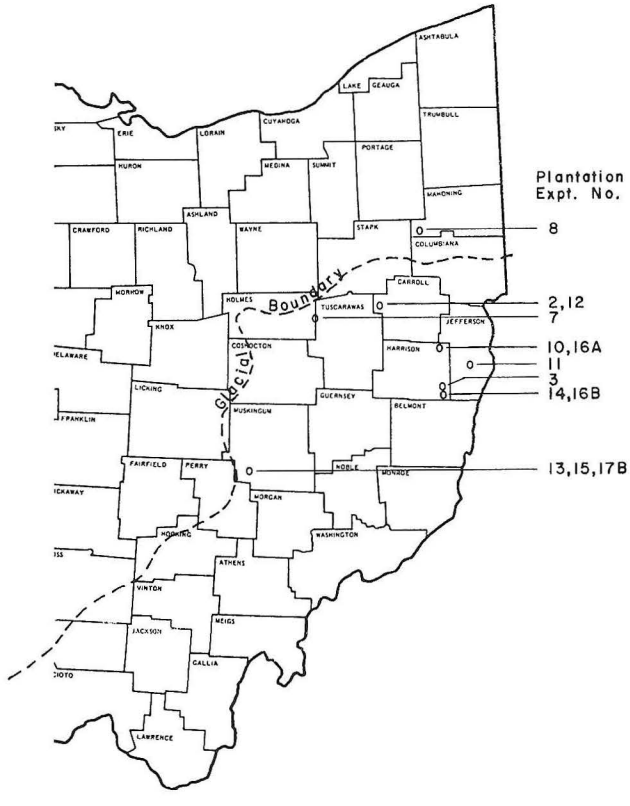


FIG. 1.—Location of experimental plantings.

3. Effects of fertilization on tree establishment and growth (Plantation 8).

METHODS

The subplots of each plantation were relocated, and a new stake was placed on at least one corner of every subplot. All surviving trees on each subplot were counted. Mean diameter and height of each species on each subplot were ocularly estimated, using diameter tape and altimeter to periodically check estimated values. All growth data presented in this report are based on these estimated subplot means. Plantation remeasurement began in mid-1975 and was completed in 1976; thus the average age of plantations was approximately 30 years.

Statistical analyses roughly followed those suggested in the establishment reports. Parts of some plantations were decimated and experimental designs were modified accordingly. In certain cases, plantation (location) effects were calculated using a split-plot experimental design. Tree measurements and resultant statistical analyses were made using English units.

In most cases, factors such as year of planting, nursery origin, spacing, method of planting, direction of furrows, and general slope and aspect of subplots are random, uncontrolled variables. Exceptions to the preceding are discussed in the results section.

Plantation numbers are original number designations found in establishment reports. In this report, the original "Plantation 3" designation is used for subplots located north of Georgetown instead of the later designation "Plantation 2.5-3".

Black and white photographs and color slides were re-taken at each photo point indicated on the original subplot maps of each plantation. Copies of these photos are on file at both the Northeastern Forest Experiment Station, Berea, Ky., and the Ohio Agricultural Research and Development Center, Wooster.

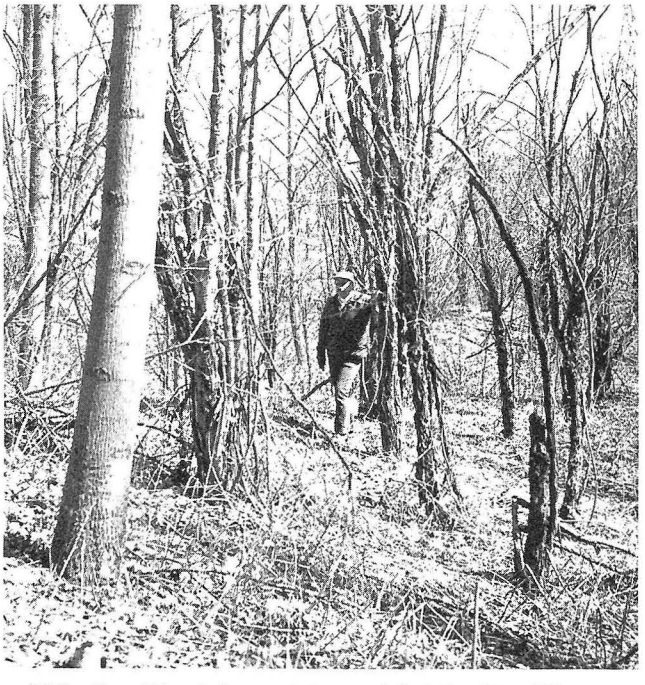
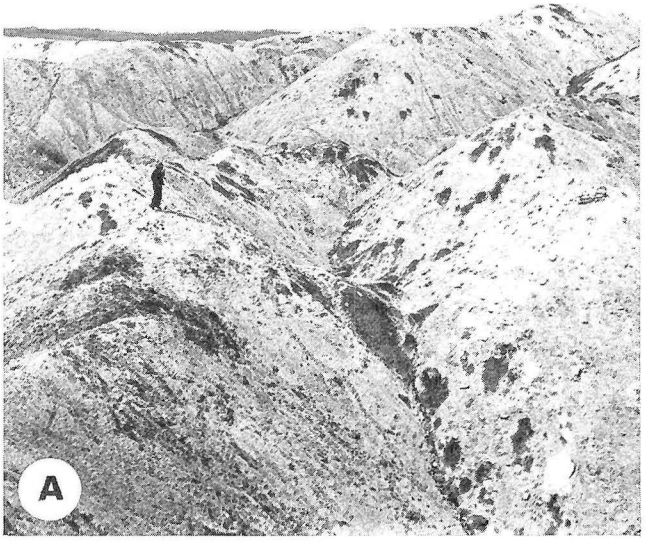


FIG. 2.—Black locust trees (right) after 30 years consisted of a clump of living and dead stems as a result of borer attack. These trees averaged only 20 ft in height. On the adjacent subplot, tuliptree (left) averaged 48 ft in height, Plantation 3 near Georgetown, March 1976. (OARDC photo)



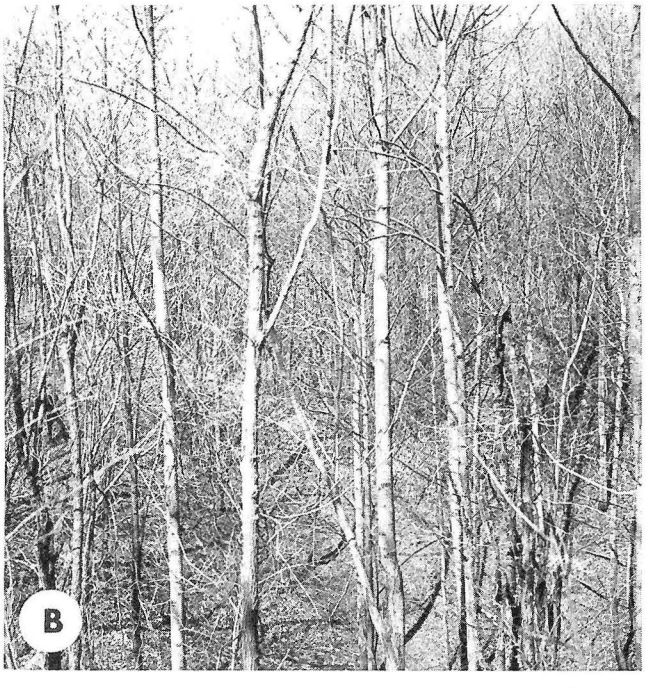


FIG. 3.—From moonscape to forest, Plantation 15 near Zanesville. (A) Subplot planted with tuliptree in 1947. Dark spots in photo described as "acid spots". (USDA Forest Service photo) (B) From same point in 1976. Tuliptree averaged 7 inches in diameter, 55 ft in height, and 68 ft²/acre basal area. (OARDC photo)

RESULTS

Species Survival, Planted Seedlings

Survival was ranked for 15 species on 10 experimental plantations (Table 2). The ranking *does not* account for differences in significant effects of plantation location (some species were planted at only one or two locations), age class of stock, spoil leveling treatments, and other variables. However, some general statements about species survival are possible, especially for species that were widely planted.

White and green ash had the highest mean survival, with both species exceeding 50% (Table 2). On Plantation 7, the only study area where these species were compared directly, they survived equally well (Appendix Tables III, IV). High survival for ash was consistent in that ash ranked first among species in seven out of eight plantations.

Survival in the 20 to 39% range was attained by some widely planted species such as osage-orange, white pine, black locust, red pine, and tuliptree (Table 2). Red and white oak survived poorly at 7.6 and 12.8%, respectively.

Six species were planted on a limited scale. Pitch pine, silver maple, and basswood survival ranged from 20 to 34%, while Chinese chestnut, cottonwood, and shortleaf pine were near failures with survival of 3 to 11%.

Performance of planted species on each plantation site is discussed in later sections. Additional data regarding species comparisons on specific plantations are given in Appendix Tables II to VII and in Figures 2 and 3.

TABLE 2. — Survival and Growth at 30 Years of 15 Species Planted on 10 Stripmine Plantations in Southeastern Ohio.

Species	Trees Planted (No.)	Survival (%)	Diameter* (in)	Height* (ft)
White ash	3320	55.8	5.0	35
Green ash	1315	52.3	4.1	27
Osage-orange	1245	39.1	2.9	20
White pine	7240	27.0	6.5	31
Black locust	11250	23.0	4.4	28
Red pine	3220	21.5	5.4	25
Tuliptree	9785	19.6	5.9	39
Red oak	3735	12.8	5.3	32
White oak	3735	7.6	4.9	31
Limited Plantings:				
Pitch pine	315	33.6	6.7	37
Silver maple	315	26.4	5.7	34
Basswood	315	20.6	5.0	28
Shortleaf pine	315	11.1	6.0	34
Cottonwood	630	8.4	6.0	35
Chinese chestnut	200	3.5	3.0	23

*Means of subplot estimates; n varied from 2 to 90.

Species Survival, Direct Seeding

In 1946, northern red oak and black walnut were direct seeded on two areas (Plantations 7 and 8). The establishment reports noted that the seed of both species was of poor quality, and the result was a near failure. In 1975, the few surviving oak and walnut trees were of similar size, averaging about 4.7 inches in diameter and 28 ft in height.

In 1947, 11 species were seeded at three locations; only six species were present after 30 years (Table 3). Bur oak survived best, with 37.2% stocking of all seedspots (Fig. 3). This was significantly higher than black walnut at 17.2%, the second best survivor. The five complete failures were all conifers (jack pine, shortleaf pine, loblolly pine, pitch pine, and eastern redcedar). These were planted at five seeds per spot plus a handful of duff from a nearby pine stand. Only a few deceased pines were found in 1976. Here again, the quality of seed was questioned in the establishment report; thus species comparisons are probably biased.

Direct Seeding on North and South Aspects

North and south aspects of steep, ungraded spoils were also seeded (Fig. 4). Mean survival values were significantly higher on south than on north aspects for bur oak and black walnut, although the mean differences were only about 15% within each species (Table 3).

The influence of aspect tended to vary by species and plantation. Black walnut survived poorly on both aspects (3% north, 7% south) of the relatively acidic spoil of Plantation 17B. Bur oak survived equally well (near 50%) on both aspects of the relatively calcareous spoil of Plantation 16B. The other seeded species in

TABLE 3. — Mean 30-Year Survival and Growth of Six Species Seeded on North and South Aspects at Three Stripmine Locations.*

Species†	Seeds per Spot	Diameter		Height		Survival		Mean Survival‡
		North	South	North	South	North	South	
	No.	in		ft		%		
Bur oak	1	4.5	6.9	28	37	30.0	44.5	37.2
Black walnut	1	4.3	3.7	31	33	8.9	25.6	17.2
Black locust	3	6.9	7.2	42	40	16.7	10.0	13.3
Black cherry	3	2.9	3.5	27	10	15.6	2.2	8.9
White ash	5	1.7	5.2	29	36	6.7	4.4	5.6
Sycamore	5	4.9	0	37	0	4.4	0	2.2

*Plantations 16A, 16B, and 17B.

†Five conifers (jack pine, pitch pine, loblolly pine, shortleaf pine, and eastern redcedar) all failed.

‡Based on number of stocked spots of a total of 180 spots seeded per species.

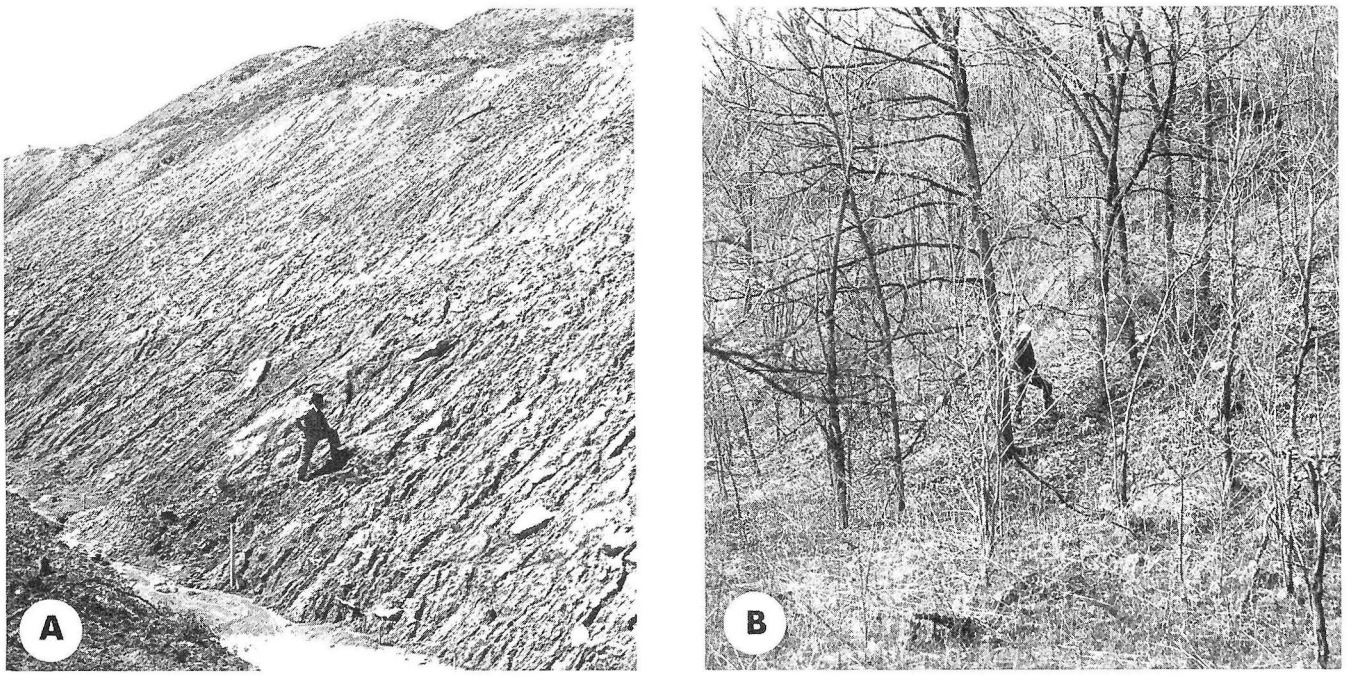


FIG. 4.—Direct seeding of tree species on strip-mine spoils, Plantation 16B near Georgetown. (A) Eleven species direct seeded in single rows up the slope, 1947. (USDA Forest Service photo) (B) From same point in 1976. Only bur oak (large trees near man) survived well. All of the smaller trees are volunteers. (OARDC photo)

Table 3 exhibited low mean survival and high variation within plantations.

Only bur oak grew in sufficient numbers to warrant statistical analysis of growth measurements. Both diameter and height of bur oak were greatest on south aspects (Table 3). Differences among mean growth values for other species were not statistically analyzed.

Age Class of Planting Stock

Various age classes of white pine, red pine, and tuliptree nursery stock were planted on Plantations 7 and 8. At both plantations, 2-2 white pine transplants survived 17 to 20% better than 2-0 white pine seedling stock, but diameter and height growth were similar among all age classes (Table 4). Likewise, 1-1 tuliptree stock survived better than 1-0 stock, but diameter and height were similar for the two classes.

On Plantation 8, survival of 2-0 red pine was double that of 3-0 stock but growth of the two groups was similar (Table 4). The establishment reports noted that 3-0 stock had a poor top/root ratio of 5.2 compared to 3.9 for 2-0 stock. The 3-0 red pine stock planted on Plantation 2 completely failed.

Black Locust as a Nurse Crop

Two large plantings, Plantations 14 and 15, were established in 1947 to evaluate use of black locust as a nurse crop for fine hardwood species. Finding out what proportion of black locust to hardwood species was best was of particular interest. Three hardwood

TABLE 4. — Survival and Growth at 30 Years of Three Species of Various Nursery Stock Age Classes Planted in 1946 on Plantations 7 and 8.

Species	Age Class	Plantation 7			Plantation 8			Mean
		Survival	Diameter	Height	Survival	Diameter	Height	Survival
		%	in	ft	%	in	ft	%
White pine	2-0	20.8	7.3	31	18.5	6.0	27	19.6a
	3-0	20.7	7.3	34	28.8	6.0	30	24.8ab
	2-2	40.9	7.7	37	35.6	6.3	28	38.2b
Red pine	2-0	4.0	5.0	25	53.0	6.0	34	28.5
	3-0	6.9	6.0	35	26.0	7.0	34	16.4
Tuliptree	1-0	13.3	6.0	38	14.0	5.0	33	13.6a
	1-1	25.1	6.3	38	21.1	4.7	27	23.1b

*Mean survival differences for age classes within each species indicated by letters a, b (Duncan's New Multiple Range Test).

species, tuliptree, "red oak", and white oak were each planted at four ratios with black locust (1:0, 3:1, 1:1, and 1:3 hardwood:locust) (Table 5, Fig. 5). The so-called "red oak" was actually a mixture of northern red oak, water oak, and willow oak, but data are treated as if one species.

Tuliptree survived significantly better than either red oak or white oak at both plantations (Tables 6, 7). Percentage survival of the oaks was not related to the ratio of black locust in the mixture, but tuliptree percentages were highest at the 1:3 (hardwood:locust) ratio in both plantations.

Species survival was also analyzed in terms of number of surviving trees on a per acre basis (Tables 6, 8). At both plantations, greater mean numbers of trees per acre were found at the 1:0 ratio (*i.e.,* pure plantings at 900 hardwood trees per acre) and least at the 1:3 ratio (*i.e.,* 212 hardwood/688 black locust planted per acre) (Fig. 4). While this trend was evident within each species on both plantations, survival rarely exceeded 200 hardwood trees per acre (Tables 6, 7).

The other side of the above ratios was also studied, *i.e.,* black locust survival when used as nurse trees on Plantations 14 and 15. Mean survival of locust was greatest (40.9%) when the black locust-hardwood ratio was 1:3 (Table 8). The influence of a particular hardwood species on black locust survival within each plantation was not significant at the 0.05 level, although the black locust planted with the tuliptree on Plantation 14 tended to survive poorly.

Inspection of tree height data indicated that effects of black locust mixtures on height growth of hardwoods were minor and did not warrant statistical analysis. Similarly, black locust heights did not appear to be

TABLE 5. — Number of Seedlings (per acre basis) and Species Ratio of Four Hardwood/Black Locust Mixture Treatments in Plantations 14 and 15.

Planted Seedlings (No./Acre) Hardwood*/Black Locust	Approximate Ratio
900/0	1:0
688/212	3:1
480/420	1:1
212/688	1:3

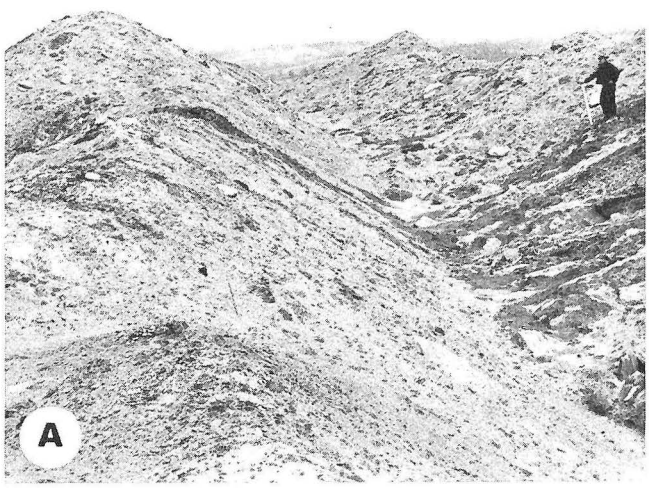
*Either tuliptree, red oak, or white oak.

TABLE 6. — Survival Values (Percent of Trees Planted and Number of Trees per Acre) for Three Hardwood Species Planted at Four Mixture Ratios with Black Locust, Plantation 14.

	Hardwood/Black Locust Mixture Ratio*				
Species	1:0	3:1	1:1	1:3	Species Mean*
			%		%
Tuliptree	16.9a	16.7a	18.9a	27.1b	20.4y
Red oak†	9.5	3.5	7.8	2.5	5.8z
White oak	4.6	4.6	2.0	1.9	3.3z
Ratio Mean	10.3	8.3	9.6	10.5	
			No./ Acre		No./ Acre
Tuliptree	171	115	91	57	108y
Red oak†	85	24	37	5	38z
White oak	41	32	9	4	21z
Ratio Mean	99a	57ab	46ab	22b	

*Significant differences at 0.05 level between ratios (rows) signified by letters a, b, c; and between species by letters y, z, Duncan's New Multiple Range Test.

†Red oak is a mixture planting of water oak, willow oak, and northern red oak.



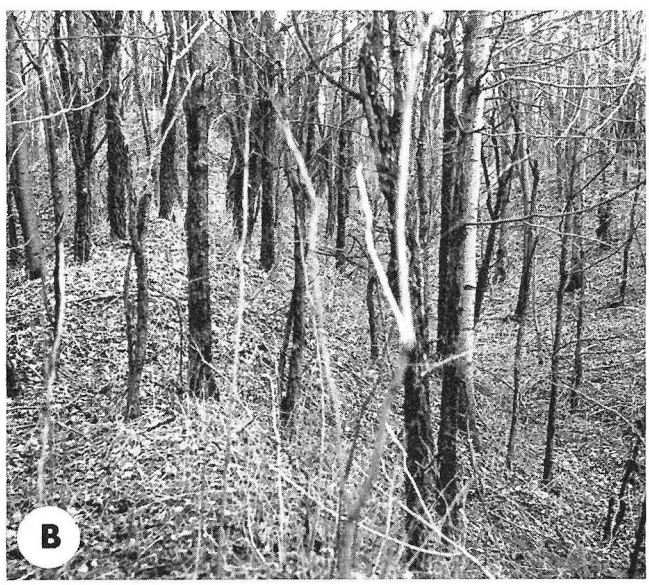


FIG. 5.—Test of black locust as a nurse crop, Plantation 15 near Zanesville. (A) Subplot planted with a 3:1 mixture of white oak: black locust in 1947. (USDA Forest Service photo) (B) From same point in 1976. Ratio of surviving white oak to black locust is 1.5:1. (OARDC photo)

TABLE 7. — Survival Values (Percent of Trees Planted and Number of Trees per Acre) for Three Hardwood Species Planted at Four Mixture Ratios with Black Locust, Plantation 15.

Hardwood	Hardwood/Black Locust Mixture Ratio* 1:0	3:1	1:1	1:3	Species Mean*
		%			%
Tuliptree	24.1a	27.7a	37.8b	83.0c	43.2y
Red oak	21.9	13.4	12.8	11.3	14.9z
White oak	6.7	9.5	6.4	7.5	7.5z
Ratio Mean	17.6	16.9	19.0	33.9	
			No./ Acre		No./ Acre
Tuliptree	217	191	181	180	192y
Red oak†	197	92	61	24	94z
White oak	60	65	31	16	43z
Ratio Mean	158a	116ab	91b	73b	

*Significant differences at 0.05 level between ratios (rows) signified by letters a, b, c; and between species by letters y, z, Duncan's New Multiple Range Test.

†Red oak is a mixture planting of water oak, willow oak, and northern red oak.

related to the hardwood species used in the planting mixture. Heights of all tree species were greater on Plantation 15 than on Plantation 14 (Table 9).

Mixed Plantings

Two mixed plantings of different designs were tested on Plantations 7 and 8. On Plantation 7, tuliptree survived at 2.2% or less when planted with black locust,

TABLE 9. — Total Mean Height* of Four Species on Plantations 14 and 15.

Species	Plantation 14	Plantation 15	Species Mean
		ft	
Tuliptree	36	43	39.7
Red oak	24	42	32.8
White oak	26	36	30.8
Black locust	21	42	31.1
Plantation mean	26.6	40.6	

*Based on subplot estimates.

TABLE 8. — Survival at 30 Years of Black Locust Planted in Various Ratios with Three Hardwood Species on Plantations 14 and 15.

Species*	Planting Ratio of Black Locust/Hardwoods Plantation 14 3:1	1:1	1:3	Plantation 15 3:1	1:1	1:3	Plantation Means† 14	15
				%				
BL/T	11.6	20.0	17.0	20.6	30.5	51.0	16.2a	34.0b
BL/RO	15.9	15.5	47.8	20.0	19.4	32.7	26.4a	24.0a
BL/WO	14.1	15.5	43.4	23.3	27.6	53.5	24.3a	34.8b
Mean‡	17.6y	21.4y	40.9z					

*Abbreviations: BL = black locust, T = tuliptree, RO = red oaks, WO = white oak.

†Significant differences at 0.05 level between plantation means within each species mixture indicated by letters a, b.

‡Total means of both plantations for each planting ratio. Significant differences at 0.05 level indicated by letters y, z.

Table 10.—Survival and Growth at 30 Years of Four Tree Species Planted in Pure and in Mixed Plantings, Plantation 7.

Age and Species of Planting Stock	Other Species in Planting Mixture*	Survival	Diameter†	Height†
		%	in	ft
1-1 Tuliptree	None	21.5	6.2	38
1-1 Tuliptree	1-0 Black locust	1.8	6.0	35
1-1 Tuliptree	1-0 Black locust and seeded black walnut	2.2	5.0	27
1-0 Osage-orange	None	28.0	2.8	19
1-0 Osage-orange	1-0 Black locust	42.5	2.7	22
3-0 White pine	None	20.9	7.3	34
3-0 White pine	1-0 Black locust	12.9	6.0	33
1-0 Black locust	None	17.8	5.3	28
1-0 Black locust	1-1 Tuliptree	32.7	5.6	28
1-0 Black locust	1-0 Osage-orange	20.3	5.0	28
1-0 Black locust	3-0 White pine	27.9	5.0	24
1-0 Black locust	1-1 Tuliptree and seeded black walnut	33.6	5.0	28

*Two species mixtures were planted in alternate three-row groups. Three species mixtures were planted in one-row groups, each species repeated every third row. Plots were 15 rows of 15 trees each.

†Based on subplot estimates.

three rows of locust alternating with three rows of tuliptree, or in alternate row mixture with black locust and black walnut (Table 10). However, tuliptree survived significantly better, 21.5%, when planted in pure stands. Conversely, black locust planted in both mixtures tended to survive better than when planted in pure stands (Table 10). Within each species, none of the mean growth differences between pure and mixed planting were significant at the 0.05 level.

On Plantation 8, tuliptree, white ash, black locust, black walnut seed, and red oak seed were planted row by row in the above order. As noted earlier, the seeded species nearly failed. Survival and growth of the planted species in this test did not differ significantly from their counterparts planted in pure stands. In both mixed and pure plantings, black locust grew exceptionally well in Plantation 8 (near Alliance), averaging 8.7 inches in diameter and 45.6 ft in height.

Leveling (Grading) of Spoilbanks

Four species were planted on subplots located on completely leveled, partially leveled, and unleveled spoilbanks in Plantation 3. Total mean survival varied little, 29 to 33% between the three leveling treatments, but significant differences within species were found (Table 11, Fig. 6).

White ash survived best of the four species, especially on completely leveled and partially leveled areas where survival exceeded 70% (Table 11). Tuliptree nearly failed (3% survival) on completely leveled areas.

Survival counts were also made in 1948, 1950, and 1955 on Plantation 3 (Table 12). By 1950, tuliptree had suffered significant losses, being the only species that had less than 50% survival. Black locust survived well through 1955 but by 1975 the original trees were well on their way to dying out. The factors that resulted in poor white pine survival at 9% on partially leveled areas or the relatively poor white ash survival on unleveled areas were not apparent in 1975. Note that white ash survival in 1955 still exceeded 90% on unleveled areas but then dropped to 43% in 1975.

Tuliptree and white pine grew best on unleveled areas (Tables 13, 14). Growth of white ash and black locust was little affected by leveling treatments (Fig. 5). A plot of mean heights of each species at various ages

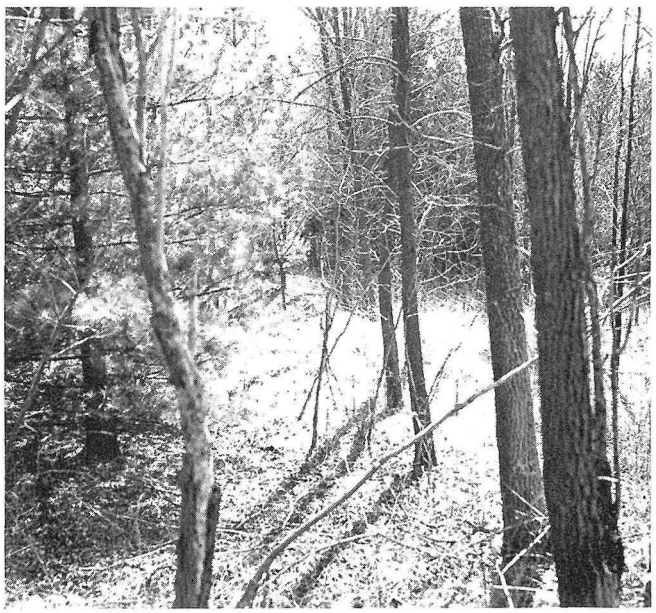


FIG. 6.—Effects of leveling differed among species. White ash (right) on this completely leveled area averaged 10 ft taller than white pine (left), while on nearby unleveled area the two species were similar in height, Plantation 3 near Georgetown. (OARDC photo)

Table 11.—Survival at 30 Years of Trees Planted on Unleveled, Partially Leveled, and Completely Leveled Stripmine Areas, Plantation 3.

Species	Leveling Treatment*			Species x̄
	Unleveled	Partially Leveled	Completely Leveled	
	%			
White ash	43b	74a	72a	63x
White pine	30a	9b	32a	24y
Black locust	15a	16b	24a	18yz
Tuliptree	29a	20a	3b	17z
Treatment x̄	29	30	33	

*Significant differences at 0.05 level between treatments within species (rows) signified by letters a, b; and between species by letters x, y, z, Duncan's New Multiple Range Test.

Table 12.—Survival at Various Dates of Tree Species Planted in 1946 on Unleveled, Partially Leveled, and Completely Leveled Stripmine Areas, Plantation 3.

Species	Unleveled				Partially Leveled				Completely Leveled			
	1948	1950	1955	1975	1948	1950	1955	1975	1948	1950	1955	1975
	%											
White ash	93	91	97*	43	94	89	†	74	93	94	85*	72
Tuliptree	77	47	36	29	75	47	†	21	61	14	6	3
White pine	90	77	67*	30	88	69	†	9	83	70	60*	32
Black locust	100	97	83*	15	100	83	†	16	100	96	85*	24
Treatment x̄	90	78	71	29	89	72		30	85	68	59	33

*Based on a sample count of 60 (20 per subplot), all other values based on total plot counts.

†Not inventoried.

Table 13.—Diameter at 30 Years of Trees Planted on Unleveled, Partially Leveled, and Completely Leveled Stripmine Areas, Plantation 3.

Species	Leveling Treatment*			Species x̄
	Unleveled	Partially Leveled	Completely Leveled	
	inches			
White pine	7.0a	4.7c	5.7b	5.8x
Tuliptree	6.7a	5.0b	4.0c	5.2y
White ash	4.7a	5.3a	4.7a	4.9y
Black locust	3.0a	1.7b	3.0a	2.6z
Treatment x̄	5.3a	4.2b	4.3b	

*Significant differences at 0.05 level between treatments within species (rows) signified by letters a, b, c; and between species by letters x, y, z, Duncan's New Multiple Range Test.

Table 14.—Height at 30 Years of Trees Planted on Unleveled, Partially Leveled, and Completely Leveled Stripmine Areas, Plantation 3.

Species	Leveling Treatment*			Species x̄
	Unleveled	Partially Leveled	Completely Leveled	
	feet			
White ash	37a	36a	37a	36.7x
Tuliptree	46a	37b	19c	34.1x
White pine	37a	26b	28b	30.2y
Black locust	20a	18a	17a	18.4z
Treatment x̄	34.8a	29.2b	25.3c	

*Significant differences at 0.05 level between treatments within species (rows) signified by letters a, b, c; and between species by letters x, y, z, Duncan's New Multiple Range Test.

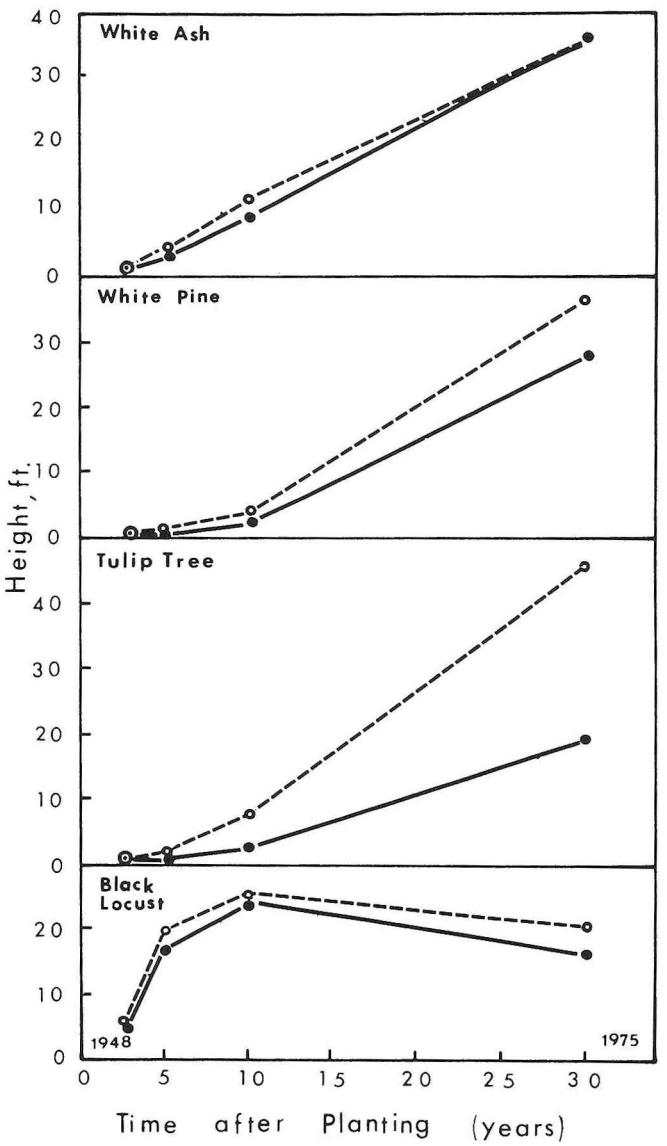


FIG. 7.—Total height of four tree species on ungraded (dashed line) and completely graded (solid line) spoils at various dates from 1948 to 1976.

on completely leveled and unleveled areas illustrates the insensitivity of white ash as contrasted to the sensitivity of tuliptree to leveling treatment (Fig. 7). Slow early growth of white pine trees and decline in vigor of black locust with age and borer injury also are apparent.

Plantation 2 (near Mineral City) also contained leveled and unleveled subplots, but almost all trees on the levled subplots had been cut down for a power line right-of-way. Survival and growth of species on unleveled subplots in Plantation 2 are given in Appendix Table V.

Seeded Grass and Legumes at Time of Planting

The purpose of Plantations 10, 11, 12, and 13 was to study the effect of seeded grass and legume species on survival and growth of tree seedlings and on soil erosion. Green ash, tuliptree, white pine, and red pine were each planted in 350 ft long rows on control subplots and on subplots seeded with a mixture of sericea lespedeza and orchardgrass (Table 1). Yellow sweetclover was seeded on additional subplots in Plantations 10 and 11 (Fig. 8). All four plantations were seeded and planted in the spring of 1947.

The establishment reports noted that grass/legume seedings failed on some portions of most subplots but these subplots were not identified. Observations in 1948 and 1955 also noted the unevenness of seeded stands on all plantations.

In 1976, seeded ground cover species were still in evidence but amount of ground cover was not measured. However, the seeded species were largely absent on subplots with good survival and growth of trees. Sweetclover was often found in open areas throughout plantations where this species was seeded (Fig. 8). Lespedeza grew in small irregular patches up to about 50 feet in diameter, and orchardgrass was present in scattered thin stands.

In results reported below, data were analyzed as if a grass/legume cover had been present in sufficient quantities, at least during the early years, to influence tree survival and growth. However, the amount of seeded

FIG. 8.—Test of herbaceous species seeded at time of planting, Plantation 11 near Bloomingdale. (A) Subplot seeded with sweetclover at 22 lb/a in 1947 and immediately planted with four tree species each in single 350-ft long rows. Note abundance of large rocks. (USDA Forest Service photo) (B) From same point in 1976. Species are (l. to r.): tuliptree (tree on left cut by beaver from nearby mine pond), green ash, red pine, and white pine. A few sweetclover plants were found in open areas outside of the row plantings. (OARDC photo)

cover species present on subplots was not measured at any time, and the results can only, at best, be considered as tentative.

Survival of tree species was significantly related to ground cover treatments. Green ash, which had the highest survival on all four plantations (Appendix Table VI), survived best on sweetclover seeded subplots (Table 15). Red pine survival was highest on lespedeza/orchardgrass subplots, and tuliptree was highest on unseeded subplots. White pine survived equally well on all ground cover types.

Table 15.—Mean Survival* of Four Species in Each of Three Ground Cover Types (Combined Data of Plantations 10, 11, 12 and 13).

	Ground Cover Type		
Tree Species	Control	Sweetclover	Lespedeza/ Orchardgrass Mixture†
		%	
Green ash	54.3 b x	67.6 a x	45.4 c x
Red pine	35.8 b y	27.3 b yz	43.2 a x
White pine	36.6 a y	35.0 a y	34.4 a y
Tuliptree	29.8 a y	19.2 b z	19.0 b z
Ground cover average	39.1	37.3	35.5

*Means followed by different letters differ at 0.05 level as follows: between ground cover types within species (horizontal) a, b, c; between species within ground cover types (vertical) x, y, z.

†Subplots seeded with a 2:1 mixture of sericea lespedeza/orchardgrass at the rate of 34 lb/a.

A significant plantation by ground cover interaction revealed that sweetclover subplots had the highest tree survival percentage on Plantation 10 but lowest tree survival on Plantation 11 (Table 16). An early measurement of ground cover density would have greatly aided in interpretation of results.

Diameter and height growth were not significantly related to ground cover treatment (species means given in Appendix Table VII). The amount of past soil erosion appeared to be minimal on both seeded and unseeded subplots in the four plantations.

Tree rows were planted at right angles with spoil ridges. Inspection of data indicated that cardinal direction of ridges did not affect tree survival or growth. The effect of position on ridge or in the valley was not examined.

Table 16.—Total Mean Survival* of Four Species† Planted in Each Plantation and Ground Cover Type.

	Ground Cover Type		
Plantation	Control	Sweetclover	Lespedeza/ Orchardgrass Mixture†
10	60.5 b w	69.1 a w	56.5 b w
11	47.1 a x	36.8 b x	49.7 a w
13	29.0 a y		26.5 a x
12	21.4 a z		12.4 b y

*Means followed by different letters differ at 0.05 level as follows: between ground cover types within plantations (horizontal) a, b; between plantations within ground cover types (vertical) w, x, y, z.

†Tuliptree, white pine, green ash, and red pine.

Survival and Growth as Related to Spoil Type

Plantations of similar design or purpose were replicated, at least in part, on calcareous and non-calcareous (acidic) spoil types. Five groups of such plantations are shown in Table 17. Three of the five groups (Plantations 2 vs 3, 7 vs 8, 10 and 11 vs 12 and 13) show a general trend for greater tree survival on calcareous than on non-calcareous spoils. Mean survival of all planted trees on calcareous spoil was 36.6%, and on non-calcareous spoil 23.3%. Survival was similar on direct-seeded areas (Plantations 16A, 16B, and 17B) regardless of spoil type. Among species, the ashes and red pine survived exceptionally well on calcareous spoils.

On the other hand, plantation comparisons show a strong tendency toward taller trees on non-calcareous spoil compared to calcareous spoil (Table 17). An exception was poor tree growth on Plantation 12, which was located on an acidic and "droughty" spoil near Mineral City and was the only experimental area with completely bare areas up to ½ acre still in existence. Generally, species such as tuliptree, white pine, and the oaks grew comparatively well on non-calcareous spoil.

Descriptions of spoil texture at planting indicated that calcareous spoils tended to be clayey while non-calcareous spoils tended to be more coarse textured and sandy. The amount of soil particles less than 2 mm diameter in spoil samples was not related to either spoil acidity or to tree survival and height growth (Table 17). However, percentage of 2 mm soil particles was always greater in the surface 0 to 6 inch sample than in the 6 to 18 inch soil depth sample within each plantation.

Methods of Planting

Three methods of planting (bar-slit, side-hole, and center hole) were compared. Tuliptree (1-1) and white pine (2-2) were each planted by three methods on Plantation 7 in 1946. Statistical analysis indicated no differences among planting methods with regard to survival. Inspection of height and diameter data revealed no important differences as related to planting methods.

Time studies of three methods of planting were also made. Statistical analysis of average time required for a man to plant 15 trees revealed the center hole method to be much slower (22 minutes) than side-hole (12 minutes) or bar-slit (11 minutes) methods. Both white pine and tuliptree required the same amount of time to plant.

Use of Fertilizer

On Plantation 8, three subplots had alternate fertilized and unfertilized rows of trees of either tuliptree, white ash, or white pine. A fertilizer mixture of 36 grams of diced meat scraps plus 4 grams of potassium sulfate was mixed with soil from each planting hole before the soil was replaced.

During the 1975 remeasurement, no attempt was made to identify which trees within subplots had been fertilized at time of planting. However, survival and growth of all trees on these subplots did not significantly differ from their counterparts growing on completely unfertilized subplots in the plantation.

DISCUSSION

The 1946-47 experimental plantings in Ohio have provided much information regarding survival and growth of several tree species on both calcareous and non-calcareous spoil types. The following species descriptions are based on results of the third year (12), tenth year (8), and present 30-year measurements. Information from other studies carried out in nearby states is also included in these descriptions.

White Ash and Green Ash: These two species had the highest survival of all planted species, averaging near 65% at 30 years on calcareous spoil, 34% on non-calcareous spoil. Height and diameter growth was poor

Table 17.—Mean Survival and Height of Trees on Plantations as Related to pH, Texture, and Percent of Soil Sized Particles in Samples. Plantations of Similar Design Are Grouped to Facilitate Comparisons.

Plantation	Trees		Stripmine Soil		Soil <2 mm in Sample	
	Survival	Height	pH	Description	0-6 in	6-18 in
	%	ft			%	%
2*	20.8	36	5.6 to 6.9	Stony, sandy loam	43	40
3*	36.0	41	>7.0 (calcareous)	Coarse limestone and clay	58	53
7†	28.7	35	3.8 to 5.5	Shaly sand and stony sand	50	41
8†	31.9	28	6.5 to 7.8	Silty, shale loam to sandy loam, glaciated area	54	44
10	62.4	30	>7.0 (calcareous)	Coarse limestone and clay	28	18
11	44.8	30	>7.0 (calcareous)	Coarse limestone and clay	31	23
12	16.9	17	<4.0 to 5.5	Coarse silt-shale and sand	46	29
13	27.8	36	<4.0 to 5.0	Coarse sandy silt loam	49	33
14	9.8	27	>7.0 (calcareous)	Coarse limestone and clay	42	29
15	21.9	41	<4.0 to 5.5	Sandy clay	48	32
16A	17.7	34	>7.0 (calcareous)	Coarse limestone and clay	46	30
16B	15.0	33	>7.0 (calcareous)	Coarse limestone and clay	46	36
17A	16.7	39	<4.0 to 5.0	Shaly silt and sand	34	21

*Mean survival and height on unleveled subplots for white ash and tuliptree combined.
†Mean survival and height for white pine, tuliptree, and white ash combined.

to fair, although little affected by soil pH or compaction. Vogel (18) notes ash species are well-suited for long-term survival, and that growth can be improved by interplanting with black alder.

Tuliptree: Survival of tuliptree was generally poor, although exceeding 40% on Plantation 15 (Zanesville). Height growth was best of all planted species (Fig. 2). Experience here and in other states (1) indicates this species is site sensitive and not suited for use on compacted soils. The tree is probably best suited for use on alkaline spoils (9). Tuliptree also is considered a good candidate for underplanting in decadent black locust stands (2).

White Pine and Red Pine: These two species have survived well, especially red pine on calcareous spoil. White pine had greatest diameter growth of all species on non-calcareous spoil. At 10 years, Finn (8) reported that the pine plantings tended to survive better on calcareous spoil than on non-calcareous, but that height growth was greater on the latter. Finn (8) also observed that none of these plantings had formed a closed canopy or accumulated much litter. At 30 years, however, closed canopies and deep litter were the rule.

Results here and in other states (2) indicate growth of pines is best when trees are planted in pure blocks rather than mixed with hardwoods. Northern seed sources are recommended for white pine stock planted north of the 39th parallel (18).

Black Locust: This species suffered a dramatic decrease in mean survival from 80% in 1955 (8) to 23% in 1975. Average height of black locust also decreased as illustrated in Figure 7, although interim measurements would be needed to render a more accurate picture of height changes within the 1955-75 period. Black locust is considered tolerant of acid spoils (9) and is widely planted to provide quick overstory cover, improve soil, and supply fence posts.

Most black locust plantings were heavily damaged by the locust borer (*Megacyllene robineae*) (Fig. 2). An exception was trees on Plantation 8 which suffered little borer damage. In order to grow black locust trees relatively free from borer attack, current recommendations are to plant trees in mixture at less than 5% of the total stand (14). In West Virginia, amount of borer injury decreases with increasing tree vigor; rapid tree growth was associated with low amounts of regrading, gentle slopes, and the relatively cool, moist north and east aspects (5).

Species Mixtures with Black Locust: First-year mortality of tuliptree, red oak, and white oak trees planted in various mixture ratios with black locust averaged 50 to 60%. The high mortality was largely due to poor quality planting stock (8). Thus, the pure and mixed plantings resulted in considerably fewer hardwoods than originally planned. After 30 years, pure plantings of hardwoods resulted in more trees per acre on subplots than when hardwoods were planted in mixture with black locust. Height growth of six planted species (tuliptree, red oak, white oak, osage-orange, white pine, and white ash) was not improved by being grown in mixture with black locust in any of the various mixture plantings.

Limstrom (11) concluded that: 1) when erosion control or soil improvement is the immediate objective, making pure plantings of black locust is the best practice; 2) mixed simultaneous plantings should not contain more than 25% black locust; and 3) underplanting black locust stands that have started to decline in vigor can be successful, although planting costs are higher. Finn (8) reported that white ash grew well when underplanted in a decadent black locust stand but both white pine and tuliptree failed. Simultaneous plantings of black locust and intolerant pine species are not recommended because the pines are quickly overtopped and also are subject to damage by the whipping action of black locust limbs (4).

Oak Species: Bur oak survived and grew best of the oak species. Survival was significantly better on south aspects than on north aspects, possibly because of warmer temperatures encountered on south slopes. Bur oak seedlings achieve maximum growth rates at temperatures near 90° F (16). The good performance here and in other tests (18) by direct seeding and planting indicate that bur oak is one of the better performing hardwoods on surface mined lands. For red and white oak, the planting material (both seeds and seedlings) was of questionable quality and survival was low. However, trees of the red oak group that were identified as northern red oak were usually larger than either white oak or other red oak species. Gebhart (9) lists red, white, and black oak as suitable for planting on alkaline spoils or soils in Ohio.

Osage-orange, Black Walnut, and Other Species: Osage-orange survived well at 61% on calcareous spoil but grew poorly on all spoil types. Seeded black walnut performed well on some areas, with up to 40% survival on south aspects of calcareous spoil. Diameter growth of black walnut was severely reduced on graded as compared to ungraded spoils in Indiana (2). The performances of pitch pine, silver maple, basswood, shortleaf pine, cottonwood, and Chinese chestnut ranged from good to poor, but these species were only planted at one location in 1 year. Additional information on the performance of these species on surface mined areas outside of Ohio was recently published by Vogel (18) and Ashby, *et al.* (1, 2).

Spoil Type: The plantation establishment reports and reports of Limstrom and Merz (12) and Finn (8) contain detailed descriptions of the stripmine soils for each plantation. In general terms, calcareous spoils of south-central Ohio consist of a compact limestone clay, whereas acidic non-calcareous spoils are a less compact mixture of sandstone and hard silty shale. Limstrom and Merz (12) reported that 10 to 17% of first-year mortality on non-calcareous spoils was due to acidity and erosion as compared to no mortality from these causes on calcareous-clay spoils. Finn (8) observed that the pines tended to survive better on calcareous spoils than on non-calcareous spoils, but height growth was greater on the latter. This trend was still evident in 1975. Also, the tallest trees of six hardwood species planted on both

spoil types were found on non-calcareous spoils. Physical, rather than chemical, factors are the probable cause of these height growth differences. High soil strength and compactibility restrict root development in the calcareous clays. The non-calcareous spoils, however, have strength, porosity, aeration, and moisture characteristics that favor root development.

Grading and Compaction: Limstrom (11) concluded that calcareous-clay spoils were more subject to compaction during grading but less subject to erosion than were sandstone-silt shale spoils. Limstrom also noted that differences in tree height between top and bottom of spoil banks were much smaller on calcareous-clay spoils than on acid-silt shale spoils.

In 1955, heights of all species except black locust were less on the graded (leveled) calcareous-clay spoils of Plantation 3 than on the ungraded area (8). Tuliptree planted on the graded area was a near failure. The continued detrimental effects of grading on height growth of tuliptree and white pine in Plantation 3 were still evident in 1975 (Fig. 6). However, grading was less detrimental to tree survival and growth on Plantation 5, an acidic (pH 5.0-7.0) sandstone-silt shale spoil (8). In West Virginia, compaction from grading also resulted in reduced height growth of black locust, tuliptree, and white pine (3). Unfortunately, Plantation 5 near Lisbon was lost to remining before 1975. The amount of compaction incurred by the grading operation is largely determined by spoil type and spoil condition (18).

Seeded Herbaceous Species: Results of seeding herbaceous species suffer from a lack of detailed observations or measurements on subplots during the early years. A progress report prepared a year after establishment of the studies (13) noted that the herbaceous seedings resulted in only sporadic, patchy stands. After 10 years, herbaceous cover was still spotty and occurred in patches (8). Remnants of these patches were found in 1976, although these were mostly located outside subplot boundaries.

Thus, findings of increased survival of green ash on subplots seeded with sweetclover, red pine with lespedeza/orchardgrass, and tuliptree on unseeded subplots are tentative at best. Finn (8) observed that trees growing between clumps of lespedeza appeared taller than trees within clumps. Other observers have noted that sericea lespedeza is a severe competitor to tree seedlings (7, 19). Vogel (17) recommends planting trees and seeding herbaceous species in alternate strips on mined lands.

An important research need is to match tree species with suitable ground cover species in order to minimize the mutually harmful effects of competition and allelopathy.

Fertilization: Ten years after planting, white ash and tuliptree fertilized at time of planting survived better than unfertilized trees (8). Also, fertilized white ash averaged 12% taller than unfertilized trees. These differences between fertilized and unfertilized trees were not apparent in 1975, although precise measurements were not made. The type of fertilizer used (diced meat plus potassium sulfate) and the size of the test (three subplots at one location) severely limit the application of these results to other stripmine areas. Vogel (18) notes that response of tree seedlings to fertilizers is difficult to predict due to differences among and within regions in geology, soils, and land uses.

SUMMARY AND RECOMMENDATIONS

Tree planting and seeding studies were established in 1946-47 by the U.S. Forest Service on a variety of stripmined areas in eastern and southeastern Ohio. In 1975 and 1976, the authors remeasured 13 of these plantings.

Summary

- Of the species established by planting seedlings, white and green ash had the best survival after 30 years. Survival of all planted trees averaged 37% on calcareous spoil and 23% on non-calcareous spoil after 30 years. Bur oak survival was outstanding among species direct seeded.
- Tuliptree had the most rapid height growth of all species tested, but was sensitive to soil compaction and had comparatively low survival. Trees of all species tended to be taller on non-calcareous than on calcareous spoils. White pine had the most rapid diameter growth.
- Black locust, a nitrogen-fixing legume, was effective in site stabilization and soil improvement but did not yield useful products because of locust borer damage. Growth of several hardwood species was not improved when planted in mixture with black locust.
- Soil compaction during grading reduced tree survival and growth.
- Survival of legume and grass ground cover, established in combination with trees, was spotty and its effects on tree species were considered inconclusive.

Recommendations

New methods need to be developed to improve productivity of mined lands for long-term production of forest crops. Successful tree establishment requires accurate assessment of site conditions, seed and seedling stock of high vigor, and use of appropriate species or species mixtures. The authors recommend:

- Evaluation of the effects on tree survival and growth of grading methods that minimize soil compaction and of post-grading treatments that reduce compaction.
- Studies of tree establishment in combination with grass and legume seedings, and of interactions between trees and ground cover seedings.
- Continued field testing of the establishment of bur oak and other oaks by seedlings and direct seeding.
- Research on planting stock characteristics and planting methods that will improve tree seedling survival on mined areas.

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APPENDIX TABLE I. — Common and Scientific Names of Plants Used in This Bulletin.

Common Name	Scientific Name
Trees	
Ash, green	*Fraxinus pennsylvanica*
Ash, white	*Fraxinus americana*
Basswood	*Tilia americana*
Cherry, black	*Prunus serotina*
Chestnut, Chinese	*Castanea mollisima*
Cottonwood	*Populus deltoides*
Locust, black	*Robinia pseudo-acacia*
Maple, silver	*Acer saccharinum*
Oak, bur	*Quercus macrocarpa*
Oak, "red"	*Q. rubra*
Oak, "red"	*Q. nigra*
Oak, "red"	*Q. phellos*
Oak, white	*Quercus alba*
Osage-orange	*Maclura pomifera*
Pine, jack	*Pinus banksiana*
Pine, loblolly	*P. taeda*
Pine, white	*P. strobus*
Pine, pitch	*P. rigida*
Pine, red	*P. resinosa*
Pine, shortleaf	*P. echinata*
Redcedar, eastern	*Juniperus virginiana*
Sycamore	*Platanus occidentalis*
Tuliptree	*Liriodendron tulipifera*
Walnut, black	*Juglans nigra*
Other Plants	
Orchardgrass	*Dactylis glomerata*
Sericea lespedeza	*Lespedeza cuneata*
Yellow sweetclover	*Melilotus officinalis*

APPENDIX TABLE II. — Survival and Growth (Ranked) of Six Species Planted in 1946, Plantation 8.

Species*†	Survival	Species	Diameter	Species	Height
	%		in		ft
Osage-orange (OO)	60.7a	BL	8.7a	BL	47a
White ash (WA)	53.3a	RP	6.5b	RP	34b
Black locust (BL)	42.7ab	WP	6.1b	WA	30b
Red pine (RP)	39.5ab	T	5.2b	WP	28b
White pine (WP)	28.2bc	WA	5.0bc	T	28b
Tuliptree (T)	14.2c	OO	3.3c	OO	19c

*Within each species, nursery stock age classes are combined. Two seeded species, red oak and black walnut, were noted to have poor quality seed and these data are excluded.

†Species means followed by similar letters do not differ at the 0.05 level, Duncan's New Multiple Range Test.

APPENDIX TABLE III. — Survival and Growth (Ranked) of Six Species Planted in 1946, Plantation 7.

Species*†	Survival	Species	Diameter	Species	Height
	%		in		ft
White ash (WA)	44.4a	WP	7.1a	T	38a
Osage-orange (OO)	34.8a	T	6.2b	WP	34a
White pine (WP)	24.3b	BL	5.3bc	WA	33ab
Black locust (BL)	22.3b	WA	5.0c	BL	28b
Tuliptree (T)	17.4b	RP	5.0c	RP	21c
Red pine (RP)	1.9c	OO	2.7d	OO	20c

*Two seeded species, red oak and black walnut, were noted to have seed of poor quality and these data are excluded.

†Species means followed by similar letters do not differ at the 0.05 level, Duncan's New Multiple Range Test.

APPENDIX TABLE IV. — Mean Survival and Growth of Ten Species Planted in 1947, Plantation 7.

Species and Stock Age	Survival*	Diameter†	Height†
	%	in	ft
Green ash, 1-0	39.4a	4.7	33
Pitch pine, 2-0	33.6ab	6.7	37
White oak, 1-0	28.6ab	6.3	32
Silver maple, 1-0	26.4abc	5.7	34
Red oak, 1-0	26.0abc	7.0	33
Basswood, 1-0	20.6abc	5.0	28
Tuliptree, 1-0	14.0bc	6.3	36
Cottonwood cuttings	12.1bc	6.3	37
Shortleaf pine, 2-0	11.1bc	6.0	34
Cottonwood, 1-0	4.8c	5.7	34

*Means followed by a similar letter are not significant at the 0.05 level, Duncan's New Multiple Range Test.

†Means not significant at 0.05 level.

APPENDIX TABLE V. — Survival and Growth at 30 Years of Four Species Planted on Unleveled Plots, Plantation 2.

Species	Age of Stock	Survival*	Estimated Diameter	Estimated Height
		%	in	ft
White ash	1-0	31.0	5.3	33
Tuliptree	1-1	10.5	7.3	38
Chinese chestnut	2-0	3.5	3.0	23
Red pine	3-0	failed		

*Each species planted on two plots at 100 trees per plot.

APPENDIX TABLE VI. — Tree Species Survival* in Percent in Each of Four Row-type Plantations Established in 1947.

Tree Species	Plantation				Species Av.
	10	11	13	12	
	%				
Green ash	91.9a x	70.2b x	33.9c x	21.3c x	54.3
Red pine	65.3a y	35.2b y	28.2bc xy	16.5c xy	36.3
White pine	53.4a y	37.8b y	31.2b xy	20.7c x	35.8
Tuliptree	31.0ab z	35.8a y	18.0bc y	9.1c y	23.5
Plantation average	62.4	44.8	27.8	16.9	

*Means followed by different letters differ at 0.05 level as follows: between plantations within species (horizontal) a, b, c; between species within plantations (vertical) x, y, z.

APPENDIX TABLE VII. — Diameter and Height of Tree Species in Plantations 10, 11, 12, and 13 Established in 1947.

Species	Diameter*	Height*
	in	ft
Tuliptree	5.2a	33a
White pine	5.8a	28b
Red pine	5.8a	26b
Green ash	3.8b	26b

*Means followed by different letters differ at the 0.05 level. Means based on subplot estimates.

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